

LIQUID DESICCANT REGENERABLE FILTERS FOR INDOOR ENVIRONMENTAL QUALITY AND SECURITY

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ABSTRACT

The goal of this work is to produce regenerable CBR filters based on innovative liquid desiccant dehumidifiers. Regenerable filters are an area of technical need. The proposed concept has the potential to advance the state-of-the-art in CBR filtration and should, at a minimum, drastically extend the service lives of HEPA/carbon systems. Conceptually, agent knockdown by electrostatic precipitation (ESP) or sorption addresses the immediate threat, and deactivation occurs over time in the liquid sump. These next generation air conditioners can use engine heat to regenerate the desiccant, are mass-manufacturable, low-maintenance, and proven highly effective. This new conditioner design shows great promise for widespread use against a broad spectrum of airborne contaminants including CBR agents.

INTRODUCTION

Background:

DOE's Buildings Technology and Distributed Energy Resources Programs have supported Thermally Activated Technology RD&D over the past several years. This research develops heating, ventilation, and air-conditioning (HVAC) equipment whose primary regeneration power input can be distributed thermal energy sources such as solar and the waste heat from onsite power generation to reduce peak loads on the national electric grid. The goals are to improve indoor air quality and maximize national energy efficiency.

One of these component technologies, desiccant dehumidifiers,¹ has been studied for its ability to scrub the air of particulates and vapors while effectively collecting water vapor. Desiccant systems can be used to ensure appropriate ventilation rates since they handle the high moisture loads found in outdoor air without expensive overcool and reheat. Packaged, solid desiccant dehumidifiers are used extensively in commercial HVAC applications where humidity control is particularly valuable, such as supermarkets and ice rinks. Liquid desiccants, lithium chloride (LiCl) salt solution, in their industrial packed spray tower configuration have been shown to be effective in collecting particulates and performing a biocidal function (>90% collection and kill of ambient bioaerosols according to one industry/university study²). LiCl solution is durable over time and at high temperatures, and its MSDS lists no health, flammability, or reactivity concerns. Industrial packed tower units are not currently suited for widespread application in commercial buildings due to their need for substantial maintenance by skilled staff. The primary components responsible for this unacceptable maintenance requirement are the mist eliminators needed to prevent entrainment of liquid desiccant droplets into the supply airflow. Our novel wet contactor core that eliminates droplet generation can open broad markets to liquid desiccant technology and bring new beneficial features to HVAC systems.

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Figure 1. Industrial liquid desiccant packer tower dehumidifier and commercial prototype

Mist Eliminators



Current Conditioner: 1500 cfm,
50 gallons lithium chloride
liquid desiccant "air washer"

Next Generation Conditioner:
1500 cfm, 1 gallon LiCl -
eliminates air washer
maintenance issues

Parallel plates impose low
resistance on supply air and
may be suitable for HEPA-
level filtration by electrostatic
precipitation

Liquid desiccant alpha unit

Because of the high potential for national energy savings DOE/NREL has been pursuing alternative liquid desiccant conditioner configurations that meet the cost and maintenance requirements of commercial building markets (commercial and residential buildings collectively consume one third of all primary energy in the US). This work has successfully produced prototype highly effective, mass-manufacturable, low-maintenance (zero-entrainment) next generation air conditioners.³ Figure 2 shows a schematic of a liquid desiccant system utilizing novel wet contactor cores (wicked parallel plates) designed to achieve these characteristics. The system employs a conditioner and a regenerator, each of which requires its own airflow. In the conditioner, supply air is dried and cooled as it comes into direct contact with the desiccant solution flowing down the wicked surfaces of the plates. Solution is collected in a sump and continuously fed to the regenerator, typically through an interchange heat exchanger to enhance energy efficiency. In the regenerator, the desiccant is heated and exposed to a scavenging airflow that carries away the moisture that the solution had absorbed in the conditioner. Wet scavenger air is exhausted outdoors and the concentrated desiccant solution is returned to the conditioner to complete the cycle. Heating of the desiccant for regeneration is the main energy input to the system. Heat sources as low as 140°F (60°C) or in excess of 320°F (160°C) can be effectively used. Waste heat sources including turbines, engine exhaust and cooling jacket water, and PEM fuel cells can be used. Industrial systems operating on a 200°F (93°C) regeneration source typically exhibit fuel-to-cooling effect Coefficients of Performance (COP) around 0.5, meaning the ratio of energy input to cooling effect output is 2-1. Commercial designs under development regenerated at 320°F (160°C) are expected to achieve COPs in excess of one. By comparison, packaged air conditioners typically have fuel-to-cooling effect COPs between 0.8 and unity, without providing the humidity control of a desiccant system. This comparison assumes an electric power generation efficiency of 30%.

Testing at NREL's Advanced HVAC Lab indicates dehumidification performance of the commercial parallel plate design is competitive with industrial packed tower design at a fraction of the pressure drop (Figure 3). Entrainment testing was also conducted using a LasairII particle sizer/counter. The data, summarized in Figure 4, indicates no discernable difference in the inlet and outlet concentrations of particles between 0.5 and 10 microns. Since the commercial prototype exhibits strongly laminar airflow, it is not expected to collect particles in the absence of electrostatic augmentation, and droplet entrainment is thereby inferred to be zero. The ChemBio Defense community has identified regenerable filters as an area of technical need.⁴ Advances in wet contactor technology for regenerable systems could provide the required air protection capability with improved HVAC characteristics.

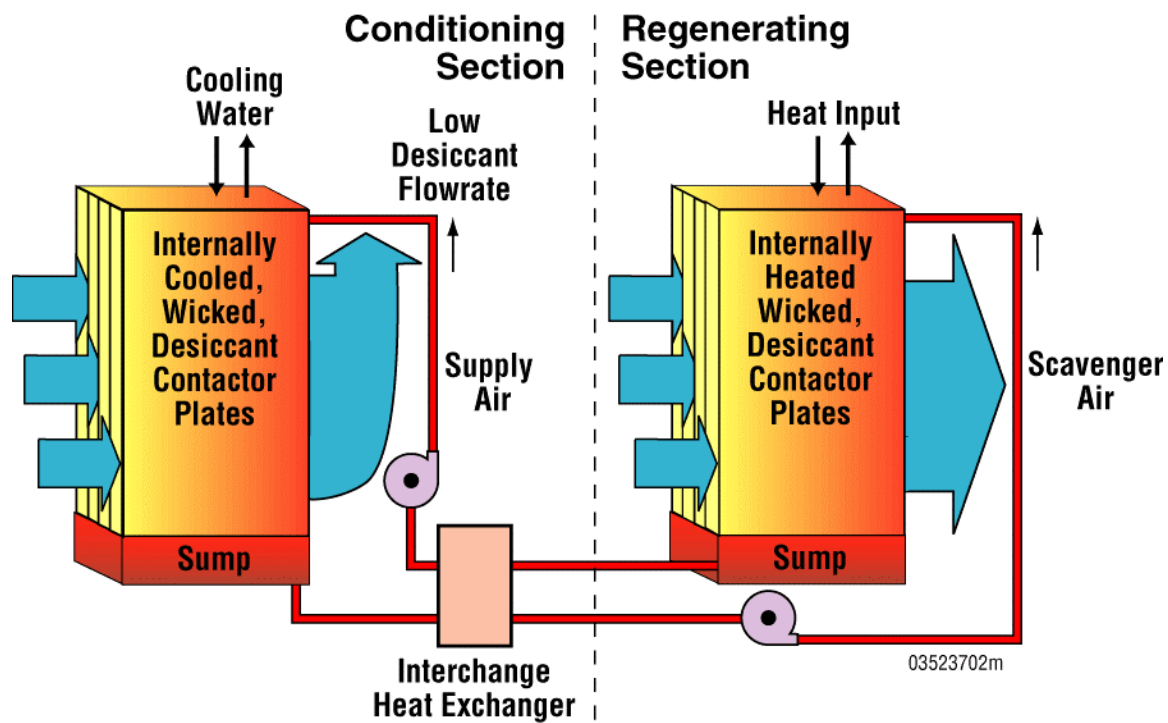


Figure 2. Commercial Liquid Desiccant Dehumidifier Diagram

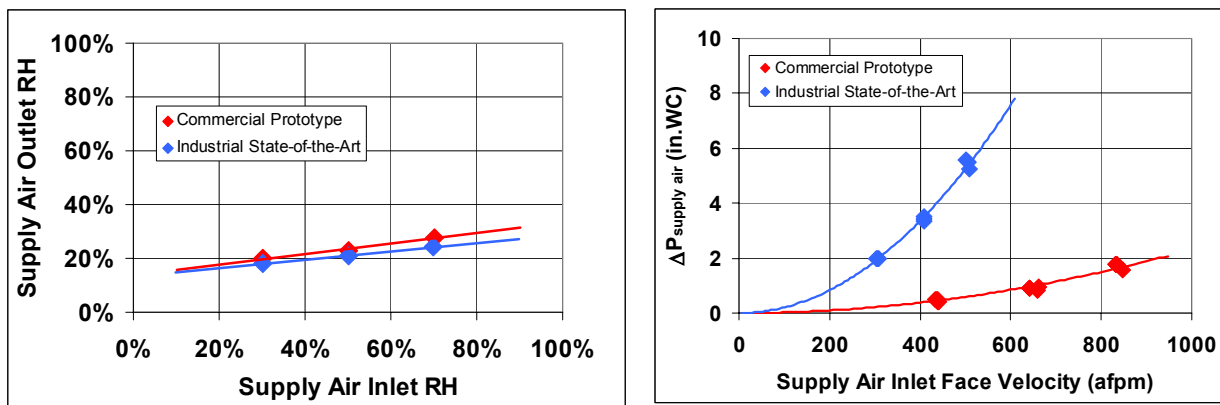


Figure 3. Commercial design dehumidification performance is competitive with industrial state-of-the-art with substantially lower pressure drop requirement

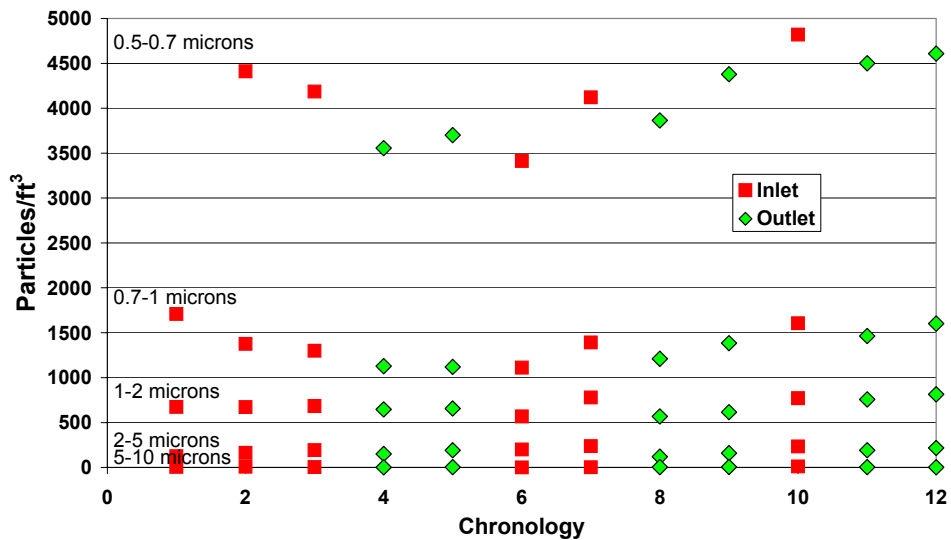


Figure 4. Comparison of inlet and outlet particle counts for the prototype system, showing no discernable entrainment of desiccant droplets

TECHNICAL STATUS

Further development has introduced innovations that expand CBR functionality.⁵ A conceptual diagram for an air protection-enabled liquid desiccant air-conditioner/filter is included in Figure 5. The system concept for air supply protection is to use electrostatic precipitation and the powerful mass transfer capabilities of liquid desiccant conditioners for CBR particle/vapor knockdown at efficiencies equal to or exceeding those of HEPA/carbon bed filters. Captured agents are retained in the solution as it circulates throughout the desiccant system until deactivated. The system operates continuously at relatively low pressure drop and electricity consumption and does not require advanced warning by CBR agent sensors to protect the supply air. Deactivation will be most rapid at the elevated temperatures in the regenerator will also occur at the lower temperatures in other parts of the system. System approaches have been proposed to further accelerate deactivation, including periodic flushing of the conditioner contacting media to expedite agent transfer to the regenerator or catalyzed kill sites and high temperature slip-stream desiccant filtration/treatment. In any case, once knockdown has been accomplished, the immediate threat of supply air contamination has been mitigated and deactivation may proceed without risk. The system continuously decontaminates itself. No desiccant is consumed to accomplish deactivation, and solution water consumed in deactivating chemical agents can be made-up with water vapor collected from the air by the desiccant. The zero-entrainment feature prevents loss of desiccant solution to the airstreams, essentially eliminating consumables.

ESP has been successfully used in wet collectors for industrial emission control.⁶ The new dehumidifier/filter core design employs parallel plates, which are highly amenable to electrostatic precipitation enhancement. Analysis conducted at MRI based on ESP theory indicates that for the current parallel plate geometry, HEPA-levels of particle capture are possible.⁷ A two-stage configuration is proposed, in which a charging grid is placed upstream of the dehumidifier core that will be electrically grounded to provide the wet collector plates. High collection efficiency of bioparticles will be aided by the finding that they are capable of holding orders of magnitude more charge than the inorganic particles ESP is usually deployed against.⁸ The analysis for our dehumidifier plate configuration predicts that a 5.6kV pre-charging grid is sufficient. This is an easily achievable with current ESP technology and 40kV systems are allowable without excessive safety requirements. An important theme in ESP theory literature, however, is that empirical testing is the only true measure of success. Each configuration must be lab validated.

We have also shown LiCl to have a thermochemically synergistic kill effect on anthrax spores and their surrogates (up to 99.99% kill and likely higher).^{9,10} We have shown the time temperature dependence on spore kill rates and considered their impacts on system design and operation. Data from these experiments are included below. The mechanism(s) responsible for this synergy have not yet been experimentally established. Desiccant solution will kill vegetative cells on contact due to the known biocidal effects of salts and dehydration and is likely to be highly effective against a broad spectrum of bio-weapons including viruses. Results from work at NREL (Figure 6) demonstrate that reductions of about 99.99% in the viable counts of *B. subtilis* and *B. cereus* spores (models for *B. anthracis*) are achieved in 4-6 hrs at 60°C in 40% LiCl solution. No reduction was observed in water. This demonstrates a clear effect of the desiccant medium. Recent work at Midwest Research Institute, subcontracted by NREL, showed a similar effect on *B. anthracis* (Figure 6).

Regarding chemical agents, desiccant technologies are inherently scrubbers for gaseous substances (water vapor and VOCs) so there is basis to believe these designs possess the mass transfer characteristics needed for effective removal of gaseous chemical agents. The drying capacity of the desiccant offers the added benefit of limiting competitive sorption by water vapor in any downstream polishing filter stages. Capture of liquid aerosol agents are expected to be similar to that of bioaerosols.⁷ Capture of chemical agents that may be dispersed as gases or liquid aerosols has not been demonstrated on this prototype, however, and the effectiveness for a given gas or vapor will depend on its molecular properties and any necessary sorbent enhancements.⁵ Destruction of chemical agents in the liquid desiccant system is expected to occur by known mechanisms of simple hydrolysis, catalyzed hydrolysis, or catalyzed oxidation resulting from action of the desiccant itself or desiccant enhanced by added metal salts or catalytic surfaces.^{7,11,12,13,14} However, known back reactions with chloride may occur due to the high chloride content of the desiccant for some agents.¹³ Baseline performance and enhancements to improve capture and destruction of chemical agents are subjects for future R&D.

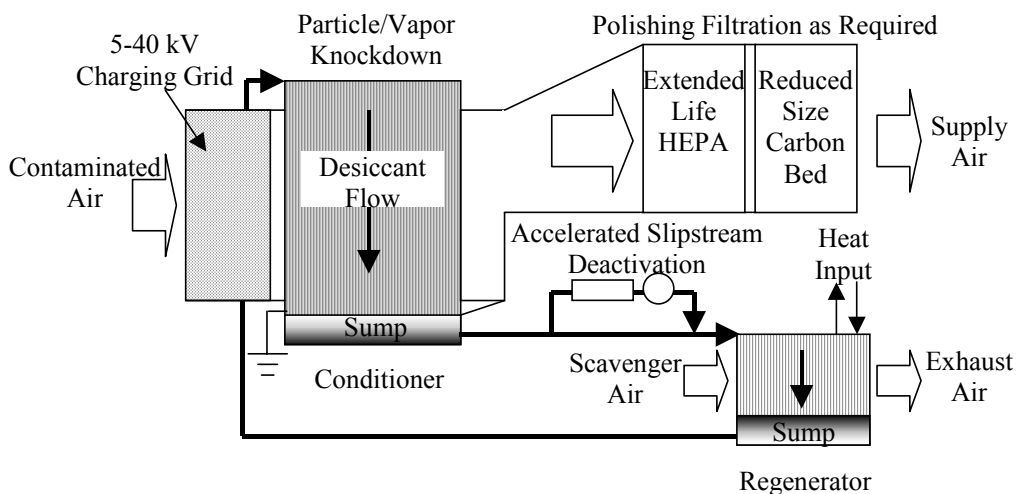
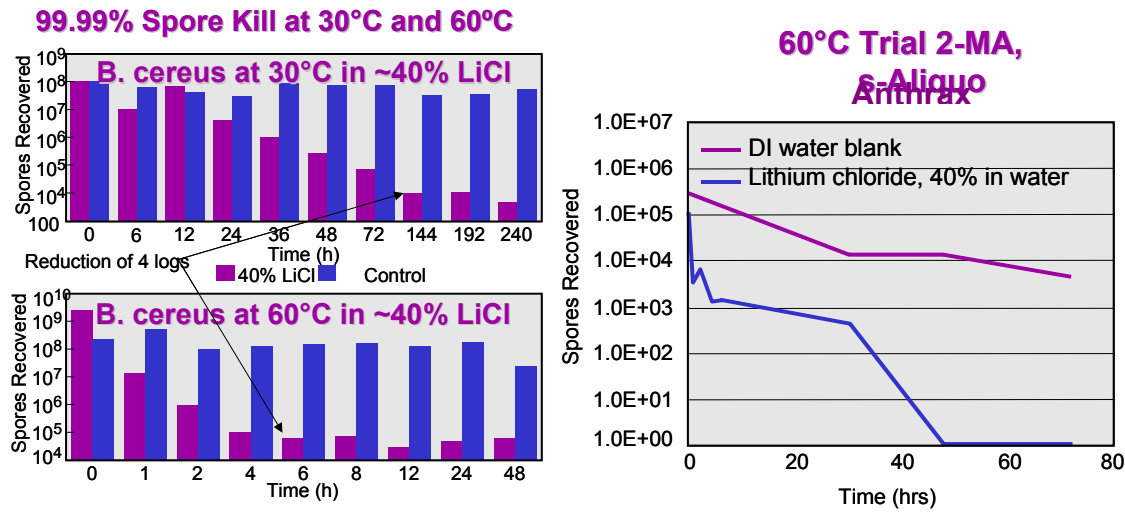


Figure 5. Conceptual diagram of a regenerable filter based on commercial liquid desiccant dehumidifier design

Figure 6. 99.99% Bacillus spore kill at 30 and 60°C and confirmation of synergy against Anthrax



CONCLUSIONS

NREL has established capture/kill status and goals at its Advanced HVAC Lab and Bioenergy Labs and through subcontract with the Midwest Research Institute (MRI) at its Bioaerosol and BioSafety Levels 2 and 3 labs. The following findings have been reached by combining NREL's capabilities in HVAC/Buildings, Microbiology, Chemistry, Air Quality Sensors, and Desiccants, along with MRI expertise in ESP/Emissions Control, Microbiology, and CBR Agent Detection.

The new conditioner design shows great promise for widespread use in supply air protection from a broad spectrum of airborne contaminants including CBR agents. Due to their multi-use functionality (Air-conditioning and Air Cleaning/Security), augmented liquid desiccant systems are expected to offer multiple advantages over state-of-the-art HEPA/carbon bed air protection systems:

- Multi-use system provides continuous humidity control benefit in addition to security function, limits competitive sorption
- Lightweight, small footprint/cube, energy efficient relative to high pressure drop HEPA/carbon bed filters
- Regenerative system reduces filter and decontamination agent consumables
- Continuous operation instantly mitigates threat upon capture without need for sensors for advanced warning of CBR attack
- Utilizes low temperature waste heat (e.g. – engine coolant or exhaust) as main energy input; potentially reduces heat signature; minimal fan/pump electric parasitics required
- Conditioner designed for robust, low-tech operation typical of HVAC technologies: 15yr life; transportable; automated controls
- Desiccant can be transported as dry, lightweight LiCl
- Commercial unit is mass-manufacturable; low-cost (<\$10/cfm)
- Thermochemical synergy proven to breach bacterial spore coat defense will also kill vegetative cells on contact due to the salt and dehydrating effects and is likely to be highly effective against a broad-spectrum of bio-weapons including viruses.
- Broad-spectrum chemical agent deactivation by enhanced hydrolysis
- Envisioned system expedites recovery of facilities after attack by limiting spread of contaminants via the HVAC system, a known, vulnerable, and highly effective means of agent delivery

ext Steps:

RD&D efforts are needed to fully assess protection levels possible as standalone or as a pre-filter for HEPA/carbon designs while also establishing advantages in terms of cost, size, energy, weight, and maintenance. R&D will focus on three main areas: (1) Particle and Aerosol Capture - Capture enhancement by ESP can begin by implementing the recommendations of MRI's design manual produced specifically for this application.⁷ Initial analysis focused on achieving Type A HEPA performance of 99.97% efficiency on 0.3 micron particles. Higher efficiencies are possible in principle and should also be in practice as this type of device can achieve high efficiencies even in the 0.001 to 0.01 micron range.¹ A diagram of the experimental charging grid is included below (Figure 7). Experimental ESP parameters must be sufficient to map a large performance domain including HEPA-level filtration. Initial testing can be conducted at NREL's Advanced HVAC Lab (Figure 8) in accordance with appropriate standards. (2) Chemical Agents - The same characteristics that enhance the capture of water vapor, small particles, and aerosols (high contact surface area and high mass and heat transfer rates) can in principal render the liquid desiccant system effective for removal of the chemical agents and hazardous industrial chemicals. Chemical agents are particularly susceptible to hydrolysis reactions as are many of the most reactive industrial chemicals.^{12,13} There are many possible approaches for targeting the sorbent/deactivation properties of the desiccant solution and the dehumidifier system to chemical agents. (3) System Packaging - The system configuration will depend on the particular applications for the technology. Once an application is identified appropriate partners will be selected to assist with integration of the liquid desiccant components into the system.

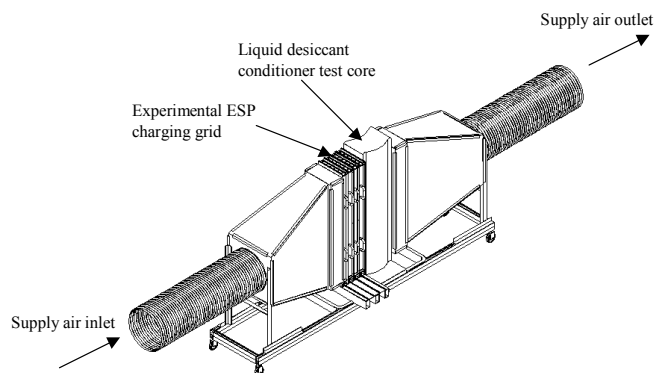


Figure 7. Experimental particle capture enhancement test section for empirical ESP design phase (power supply and particle counters not shown)



Figure 8. High-speed, high accuracy evaluation of full scale HVAC/air cleaning equipment at the NREL Advanced HVAC Laboratory

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